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GETTER-ION PUMPS

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GETTER-ION PUMPS

The term 'getter-ion pump' denotes any high-vacuum pump which utilizes both 'gettering' and ionization to provide permanent trapping (pumping) of gas atoms and molecules. The word 'getter' comes from the vacuum tube industry, where it has been used for years to denote reactive metals and alloys which are used inside vacuum tubes. In a tube, the getter is evaporated at pinchoff and serves to improve the existing vacuum by trapping additional gas molecules. This is simply the principle of chemical bonding. The newly evaporated film of getter material, which is usually barium or a barium alloy, on the wall of the tube, combines chemically with non-noble gases which strike it. These molecules or atoms are thereby removed from circulation and prevented from reacting with the tube's cathode.

The term 'getter-ion pump' is applied to vacuum pumps because of the close analogy with vacuum tube getters. Ionization is added because without it, noble gases such as argon cannot be pumped. Since air contains approximately 1% argon, it is absolutely essential that a pump be able to pump argon, in order to achieve a high vacuum when pumping air. Therefore, although ionization plays a relatively minor part in the gas-trapping mechanism of any getter-ion pump, it is indispensable.

It should be pointed out that gas trapping always occurs at the solid surfaces inside the pump. There are essentially no collisions between titanium and gas molecules in flight. The trapping only occurs when gas atoms, molecules, or ions strike a surface on which titanium has been deposited. When this happens, they usually stick, unless the surface has already become saturated by combination with gas particles which arrived earlier.

A. Magnetic ion pumps

1. The Penning Gauge

The common commercially available magnetic ion pump, whether it is called a diode, triode, or whatever, is a sputter-ion pump. It is based on the Penning gauge, which was invented at the Philips research laboratory in Holland and is also known as the Philips or cold-cathode gauge. The principle on which it depends is that of a cold-cathode discharge in a magnetic field.

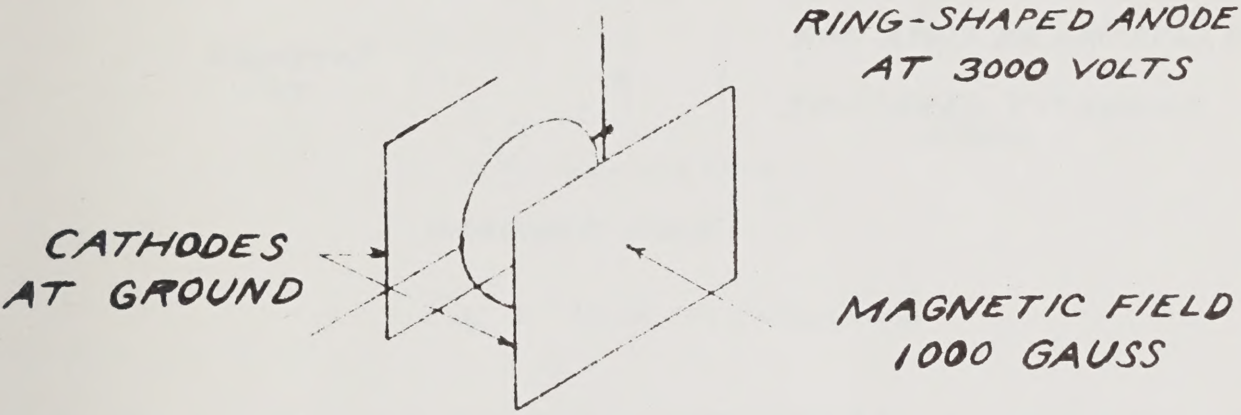


Fig. 1. Penning gauge design

Electrons are ejected at random from the cathodes by cosmic rays or radioactivity. They are attracted to the anode but are in general constrained to spiral about the magnetic field and oscillate back and forth between the cathodes. They collide with gas molecules, and as a result of these collisions additional electrons are liberated and a self-sustaining discharge occurs.

2. The diode ion pump

The operation of the diode ion pump is identical to that of the Penning gauge, and it is used as a gauge and pump simultaneously. The positive ions formed in the discharge bombard the cathodes, ejecting metal atoms. These atoms, which are uncharged and therefore unaffected by the electrical and magnetic fields, are deposited chiefly on the anode surfaces, since these constitute

most of the surface in the vicinity of the cathode. In this way, a continuously replenished film of reactive metal is formed on the anode and traps neutral gas particles. This trapping of neutral gas atoms and molecules by the sputtered titanium is the principal pumping effect. It accounts for the pumping of active gases, such as nitrogen, oxygen, and others.

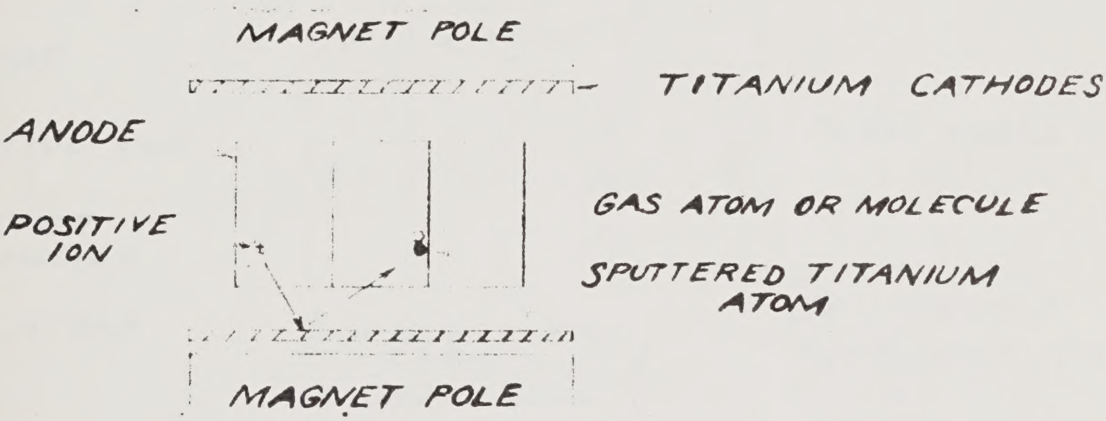


Fig. 2. Diode ion pump design

Noble gases, such as helium and argon, are pumped by ion burial in the cathodes. Hydrogen is also pumped in this way, because it sputters very poorly but penetrates the cathode lattice structure readily on account of its small size. Sputter-ion pumps react in certain distinctive ways to the noble gases and to hydrogen, deuterium and tritium. All sputter-ion pumps, whether diode, triode or whatever become saturated after extensive pumping of hydrogen, deuterium, or tritium (which we can abbreviate H, D, and T.). These elements are pumped almost exclusively by burial in the cathodes, and as this process continues, the cathodes become saturated. Finally, they swell up to such an extent that they develop actual cracks. Concurrently, the pumping speed for H, D, or T drops off to zero. The pump must then undergo a very long bakeout to remove most of the H, D, or T, or the cathodes must be replaced.

3. The triode ion pump

Diode ion pumps will not pump argon-rich atmospheres stably for any length of

time beyond a few minutes, except at extremely low pressures and the smallest possible argon flow rates. This is because previously buried argon atoms begin to be re-emitted almost immediately by the newly-arriving argon ions. The so-called 'triode' pump, shown in Fig. 3, was developed to provide better pumping for argon.

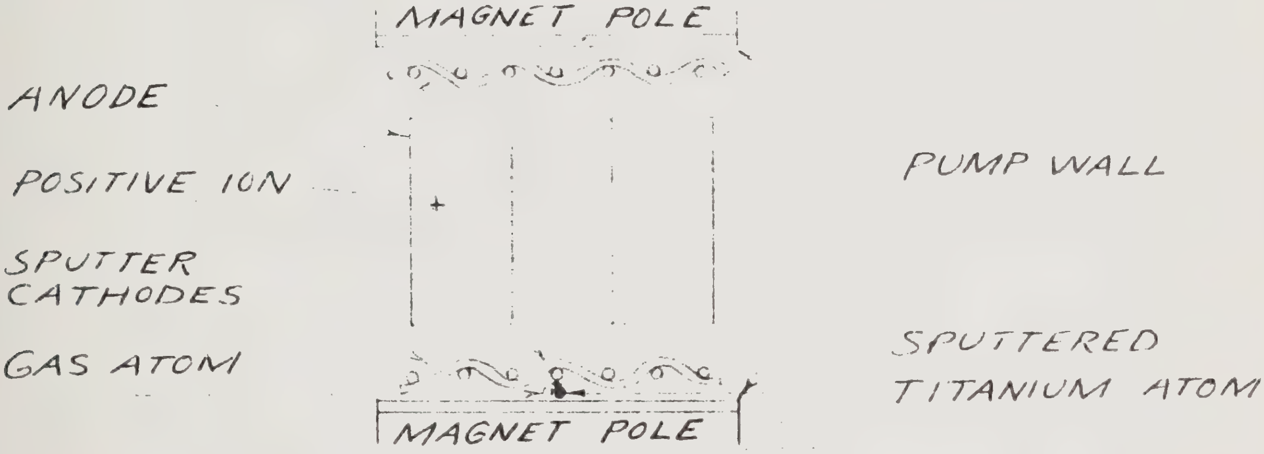


Fig. 3. Triode ion pump design

The ions lose their charge at the cathode, but continue to travel to the wall of the pump on account of their momentum. However, they arrive at the wall with low energies, and produce little or no sputtering. Titanium, which is sputtered from the edges and sides of the cellular cathodes is ejected chiefly in the forward direction and also is deposited on the wall. It therefore covers ions which have been previously deposited on the wall (after losing their charge at the cathode). The ions (which are now uncharged atoms) are prevented from escaping by the coating of sputtered titanium. The pumping speed for argon can therefore be an appreciable fraction, up to 1/3, of the speed for air.

A serious disadvantage of the triode pump compared with the diode is the cathode construction used. The wire mesh cathodes used in triode pumps provide only a very small quantity of titanium. The life of such cathodes is only a small fraction of the life of solid cathodes. In fact, if the pump is operated for any appreciable time in the micron range, during starting, the ion beam may melt the wires of the mesh.

In addition the triode is, of course, subject to the other severe limit-

ations of sputter-ion pumps in general:

1. Can only be used at very low gas flow rates.
2. Particularly susceptible to stalling under the effect of gas bursts or even moderate gas loads of any duration.
3. Often difficult to start, especially when old.
4. Very expensive, heavy, and bulky.

A form of diode pump, developed to improve the pumping of argon present in [illegible] is shown in Fig. 4. This structure eliminates the so-called 'argon instability' which occurs in diode pumps when a steady inflow of air is pumped at 1 x 10^{-5} torr over long periods of time. However, it will not pump pure argon stably at all, and furthermore so much material is removed from the cathodes that after 4,000 hours at 1 x 10^{-5} torr, the ion beam drills a hole through the cathode and through the pump wall.

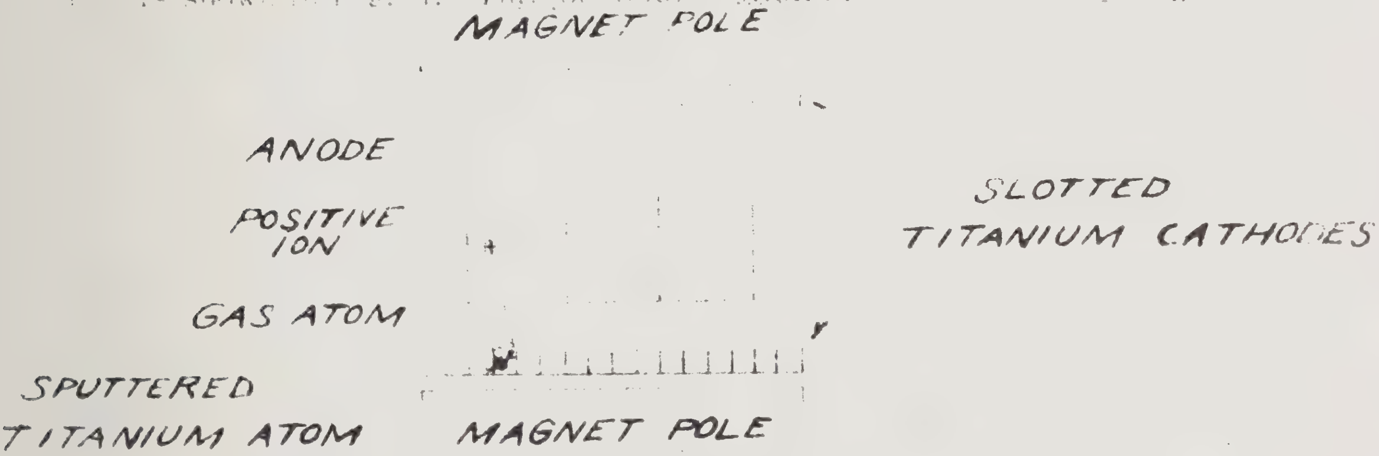


Fig. 4. Slotted cathode pump.

The disadvantages of magnetic sputter-ion pumps, as well as their advantages, stem from their basic physical mechanism: cold-cathode sputtering. The limiting factor in determining their pumping speed is the sputtering rate. This is always low, and in practical pumps only nominal increases can be obtained without introducing undesirable effects. The sputtered deposits are saturated by gas molecules almost as rapidly as they are formed. There is never at any

time a surplus of unsaturated titanium to absorb sudden gas bursts, and this is the reason why pumps of this type are very susceptible to stalling. Their pumping speeds and throughputs, expressed in terms of pump volume, are very low, and pumps with appreciable speeds are very large and heavy.

B. Titanium sublimation pumps

In view of the basic limitations of sputter-ion pumping, efforts have been made in recent years to explore other getter-pumping techniques. Thermal evaporation or sublimation of titanium has been recognized for years as providing very high pumping speeds for active gases. Almost any desired speed can be achieved, limited only by the area over which titanium is deposited. Professor R.G. Herb of the University of Wisconsin was the first to use titanium in a getter-ion pump. He began work in the early 1950s on a series of electrostatic getter-ion pumps which made use of the evaporation of titanium plus ionization which was produced by means of a highly transparent grid structure. These came to be known as Evapor-Ion pumps.

Unfortunately, the dependence on evaporation rather than sublimation meant that the Herb pumps were of very limited practical value. Evaporation is the conversion of matter from the liquid state to the vapor state, and liquid titanium is one of the most reactive substances known. It turned out to be practically impossible to prevent the titanium from reacting with various structural elements within the Evapor-Ion pump, which resulted in early mechanical failure. Another serious disadvantage of evaporation is the high temperature required. Heat is the enemy of high vacuum, because of the outgassing effects which it produces. It is therefore desirable to operate at as low a temperature as possible, and this cannot be done if evaporation is used.

The only proven and useful method for depositing titanium at high enough rates to produce rapid pumping is sublimation. This is the conversion of matter

from the solid state to the vapor state, below melting. Titanium can be sublimed at high rates below its melting point and this makes sublimation pumping feasible.

1. ANDAR's magnetless appendage pump

A simple form of electrostatic sublimation pump is shown in Fig. 5. This is ANDAR's magnetless appendage pump, which uses an electron beam to cause ionization and sublimation. This device is particularly useful in maintaining a high vacuum in a sealed-off vacuum apparatus, such as a special-purpose vacuum tube or a vacuum-jacketed cryogenic transfer line.

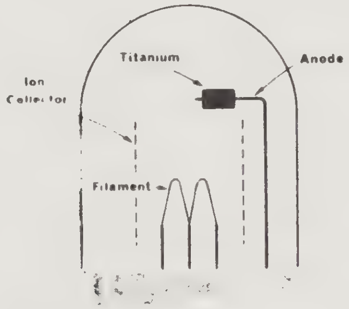
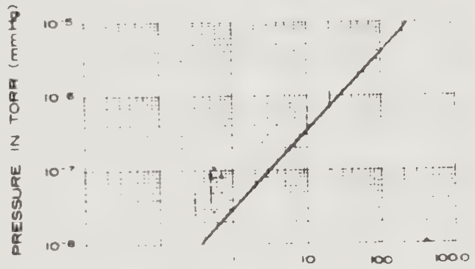


Fig. 5. ANDAR electrostatic appendage ion pump

The basic principles involved are ionization and titanium sublimation. Electrons emitted from a tungsten filament near the center of the pump are attracted to the anode, which operates at a positive potential of about 3 to 6 kv. The precise value depends on the emission current. The electrons heat the titanium target, on the anode, to high enough temperatures to cause the titanium to sublime appreciably below melting. The sublimed titanium is deposited on the ion collector and on the glass, chiefly the latter. These titanium deposits are very reactive chemically, and they trap gas molecules and ions permanently. This is the pumping action.

Ionization is caused by collisions between electrons and gas molecules. The ions so formed are attracted chiefly to the ion collector, which is near ground potential. The rate of ion production and collection varies with pressure, which allows the pump to be used as a vacuum gauge. It has been calibrated in terms of pressure vs. current for an emission current of 1 ma. A calibration curve is shown in Fig. 6.



Ion collector current- millimicroamp
at 1 ma emission

Fig. 6. Calibration curve

In a typical application, on an image-intensifier tube, the pump is operated by means of a cycle timer which turns it on for one 30 minute period each 24 hours. This is adequate to maintain a good vacuum in the tube and it insures very long pump life. It is usually preferable to operate sublimation pumps in an on-off manner for optimum results, particularly at ultrahigh vacuum. Pumping action for non-noble gases continues even after the power is shut off, which is one of the principal advantages of this kind of pump as compared with the magnetic sputter-ion type. This is due to the reactivity of the sublimed deposits, which cover several square inches and have intrinsic pumping speeds of 10-15 liters/sec. square inch.

The advantages of the electrostatic appendage pump compared with magnetic pumps may be summarized as follows:

1. The sublimed layer continues to pump even with the power off.

This results in a greatly decreased rate of pressure rise, which is very important where long tube shelf life is required.

2. Little or no pressure rise occurs when the pump is turned on after being off for hours.
3. No magnetic field.
4. Light weight.

2. Composite Sublimation Sputter-ion Pumps

Within a relatively short time after the introduction of the sputter-ion pump in 1958 it became apparent that its disadvantages were serious enough to limit severely its prospects for future growth. Accordingly, intensive efforts were made to augment its capabilities by the addition of auxiliary techniques such as cryogenic pumping and titanium sublimation. The latter was accomplished by means of resistance-heated filaments composed of tungsten wire wound with titanium and molybdenum. This method, introduced commercially by Hall in 1961, has been very successful and has awakened renewed interest in sublimation as a pumping technique. Its chief disadvantage is the short life of the filaments; another weakness is that it provides no help in pumping noble gases.

The success of titanium sublimation in producing any desired pumping speed for active gases at a fraction of the cost of sputter-ion techniques has led to a re-examination of the entire approach to getter-ion pumping. Since we now rely on sublimation for the major portion of the pumping in any composite sublimation sputter-ion pump, it is logical to think of such devices as basically sublimation pumps, with the sputter-ion portion playing a secondary role.

THE TORRGETT* TITANIUM PUMP

The Torrgett pump, unlike all previous composite pumps, has been designed from the outset as a single, integral pump which is based on the electron beam sublimation of titanium. It therefore obsoletes previous forms of composite

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* ANDAR Trademark; patent applied for.

pumps, all of which are constructed by simply adding a sublimation chamber to a standard sputter-ion pump. Their sublimation chambers utilize short-lived, low-capacity resistance-heated titanium filaments, and cannot be integrated with the sputter-ion pump because of the nature of the latter. Each filament provides less than 0.5 grams of useful titanium, as compared with 8 grams or more in each anode of the Torrgett. With the Torrgett we have for the first time a sublimation pump in which the sublimator can be operated for months without having to replace elements. It is therefore the first truly long-lived high-speed getter-ion pump.

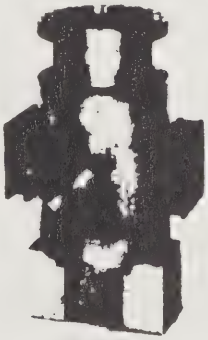

Fig. 7. Torrgett titanium pump.

The design of the Torrgett pump is such that titanium is sublimed directly onto the cathodes of the sputter-ion cell, as well as onto the wall of the cylindrical pump body. The purpose of this is to improve the pumping of noble gases and also, because of this improvement, to enhance the pumping of air with its 1% of argon. The reason for the improvement is that argon ions which have already been buried in the cathodes are prevented from being re-sputtered. The sublimed titanium provides a "plastering" effect and protects the surfaces of the cathodes from further bombardment. This effect was demonstrated several years ago by Brubaker and by Kornelsen, but this is the first time that it has been incorporated into a practical pump. Fig. 8 shows the internal detail of the Torrgett sublimator and sputter-ion chamber.

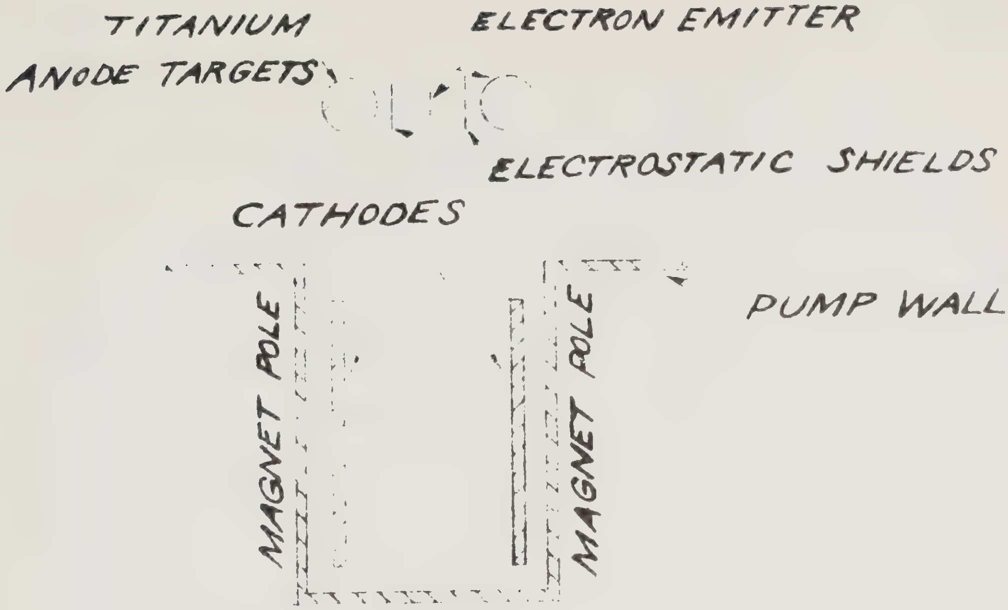

Fig. 8. Torrgett pump internal detail

As can be seen from the figure, the sputter-ion cell is made as large and open as possible, consistent with the magnetic field requirements. This can only be done by eliminating all internal anodes. The only electrodes in the pump are now the cathodes, therefore this form of sputter-ion pump might be called a 'unode'. The electron bombardment technique allows us to use massive titanium targets and, in addition, the titanium is sublimed much more efficiently than in the resistance-heating method. Because the heat losses per gram of titanium are very much less from a bombarded target than from a resistance-heated sublimation filament, the power consumption per gram of titanium is only a very small fraction of that required by the older technique. This, coupled with the much greater amount of titanium available in the bombarded targets, insures vastly longer life.

Just as in the case of resistance-heated filaments, catastrophic melting must be prevented. With this in mind, a structure has been devised which greatly increases the stability of the target and provides long-term maintenance-free operation. This structure is a composite of titanium and molybdenum, and makes use of the surface tension of molten metals. If any local melting of titanium occurs, its surface tension causes it to be confined by the molybdenum. If any molybdenum dissolves in the titanium, the melting point of the latter is increased, which improves stability.

COMPARATIVE FEATURES OF THE TORRGETT AND OTHER TYPES OF IONIC VACUUM PUMPS

a. Magnetic sputter-ion pumps

As pointed out earlier (p. 5), unaided sputter-ion pumps can be used only at very low gas flow rates, because of their tendency to stall under the effect of gas bursts or even moderate gas loads of any appreciable duration. The reason for this is that sputtering is a very slow process, and therefore there is never any appreciable amount of unsaturated titanium present. In the absence of some other source of titanium, such as sublimation, the usefulness of a sputter-ion pump is very limited. It cannot in general be substituted directly for an oil diffusion pump of the same rated speed, because of this poor gas-handling capability.

The situation with the Torrgett is very different. Titanium sublimation provides a large surface of active titanium, which can be renewed as rapidly as desired. This active surface acts like a sponge for gas molecules, and can adsorb large numbers of them. An unsaturated titanium surface at room temperature is rated conservatively at 10 to 15 liters/sec/sq. in. for nitrogen, and 25 to 40 liters/sec/sq. in. for hydrogen. This figure expresses the rate at which gas can be pumped at the surface, once it has arrived there. The internal pumping speed of a 500 liter/sec. Torrgett pump is therefore 2500 liters/sec or more. Because of this, it can easily handle gas loads which would quickly stall a magnetic diode or triode pump rated at 500 liters/sec. The internal pumping speed of a 500 liter/sec magnetic pump is little more than 500 liters/sec.

Another weakness of the standard magnetic ion pump is its tendency to deteriorate in performance characteristics as it ages. Even a new pump may be slow starting, and as it grows older the situation becomes worse. In addition, the ultimate vacuum usually becomes steadily poorer, particularly if anything

except clean dry gases are being pumped.

The reasons for the deterioration in characteristics stem from surface properties. Taking the starting problem first, the following comments can be made: Conventional magnetic pumps utilize internal anodes, with considerable surface area. Most of the sputtered titanium is deposited on these anode surfaces, and the deposits become thicker and rougher with time, thus further increasing the surface area. Each time the pump is exposed to air at atmospheric pressure, layers of gases are adsorbed, of which water vapor adheres most tenaciously. When the pump is turned on at roughing pressure, the electrons which bombard the anodes cause them to heat up, desorbing the previously adsorbed water vapor and other gases. Because the anodes are thermally isolated from their surroundings, heat transfer is poor, and desorption effects can become quite severe.

Positive ions cause even stronger and more rapid outgassing effects than electrons, during the starting of conventional magnetic ion pumps. Most such pumps are negative ground devices, which results in all of the pump's wall surface being subjected to heavy bombardment by positive ions in the glow discharge which accompanies the starting phase. Gases adsorbed on the walls are immediately returned to the gas phase by the impinging ions, and this constitutes an additional load which must be pumped. The glow discharge during starting of conventional ion pumps often fills the entire system, and such pumps can be very slow in starting.

In contrast, the magnetic ion pump which forms part of the Torrgett operates at positive ground, with no internal anodes. The body of the pump forms the anode. When this pump is started at roughing pressure, after exposure to atmospheric air, only the titanium cathodes, which are at a negative high voltage, are bombarded by ions. The amount of re-evolution of gas is very much less. Furthermore, the anode, which is the pump wall, is in contact with ambient air and therefore is not heated nearly as strongly. The net result is

that starting is much smoother and faster. The glow discharge remains confined to the inter-cathode region and does not even escape into the body of the pump. The Torrgett thus combines the optimum starting characteristics of ANDAR's proprietary ion pump with the high pumping speeds and gas-handling capability of titanium sublimation.

The susceptibility of a magnetic ion pump to contamination is due to its large internal wall area. The walls grow progressively more contaminated as time goes on; the rate, of course, depends on the amount and kinds of contaminants which enter the pump. The only way in which this process can be reversed, without removing the pump from the system, is by bakeout. This is usually accomplished by means of an internal heater, which adds to the cost of the pump and introduces an additional element which can lead to future failure. As soon as bakeout is terminated, the contamination process begins anew.

The situation in a Torrgett pump is very different. Here the internal surface consists chiefly of titanium, which is constantly being renewed by sublimation. Contaminants are covered by titanium, with which they form chemical bonds and are thus permanently trapped. The deposition of titanium has been shown to have the same effect as bakeout and therefore the walls in a Torrgett pump are as clean as if they were undergoing continuous bakeout. In fact, the walls at all times act as a sink, rather than a source for gas.

b. Electrostatic ion pumps.

Pumps have been made which depend solely on electrostatic evaporation or sublimation of titanium, without magnetic fields, and there are certain specialized applications for which this may be required. However, such pumps have certain serious limitations. They cannot be used as pressure gauges, and they must usually be water-cooled. They are sensitive, requiring careful handling in order to prevent burnout during starting at roughing pressure. If anything happens to the sublimation mechanism, the pump must be shut down and repaired. The sublimator cannot be operated in an on off sequential manner, because as soon as the sublimator is shut off the pressure rises. On-off operation is the most efficient way to use titanium sublimation, at high and ultrahigh vacuum, and the Torrgett is ideally suited to this. Its

electronic timer permits independent control of on - and off - times.

The purpose of the sublimator timer is to obtain the best vacuum with the lowest possible rate of titanium consumption. Sublimation pumping is a competition between gas trapping, caused by the sublimed deposits, and gas evolution, caused by the outgassing of various parts of the structure as a result of the heat used to produce sublimation. Now as the pressure decreases, the rate of titanium sublimation required also decreases, because there are fewer gas molecules to trap. As it turns out, instead of continuing to operate the sublimator 100% of the time and decreasing the power input, it is much better to keep the power approximately constant and operate the sublimator less than 100% of the time.

On-off sublimator operation can only be performed if some other form of pumping, such as the sputter-ion pump, is present and operating continuously. The sublimator and sputter-ion pump thus make an ideal combination, preserving the best features of each. On-off sublimator operation minimizes the consumption of titanium and thereby minimizes the buildup of flakes and the necessity for maintenance.

To summarize the characteristics of the purely electrostatic ion pump, its advantages and disadvantages can be listed as follows:

Advantages

1. No magnetic field.

Disadvantages

1. No pressure-measuring capability; the device is only a pump.
2. Price is higher than combination sublimation-sputter-ion pumps, despite the lack of pressure-measuring capability.
3. Must be water-cooled.
4. Consumes more titanium than necessary, because it cannot be cycled on-off.
5. Internal structure is fragile and easily damaged.

Applications

The Torrgett is the only getter-ion pump which combines the high pumping

capacity of sublimed titanium with long life and ease of operation. It pumps pure noble gases stably. It is the only sublimation-type pump which is also a vacuum gauge. This remarkable combination of characteristics gives it unique versatility, and allows it to compete in a very wide range of applications. Among those areas in which the Torrgett will provide superior performance are the processing of various kinds of vacuum devices such as tubes, relays, switches and capacitors, the processing of semiconductors, the pumping of particle accelerators and scientific instruments, including mass spectrometers, the processing of gas laser tubes, the deposition of thin films for electrical and optical purposes, and a wide variety of research applications including high-temperature high-vacuum testing of materials, space simulation, and many others.

The Torrgett has been successfully field-proven in production applications involving widely diverse requirements. In one such application it has outperformed the combination of a much larger conventional magnetic ion pump and a resistance heated sublimator. In another, it has been used to process gas laser tubes, operating in an atmosphere of 95% helium - 5% neon, with no problems whatsoever. Only oil diffusion pumps had previously been used for this purpose.

The outstanding simplicity, versatility and pumping power of the Torrgett have already enabled it to penetrate areas which were formerly closed to ionic vacuum pumps. In the future its horizons can be expected to open even wider.